LUNAR PB. A. A. Nemchin[1,2], J. F. Snape[1], M. J. Whitehouse[1], M. Norman[3], J. J. Bellucci[1], H. Jeon[4], M. Kilburn[4], M.L. Grange[1,3], and F. Thiessen[1], [1]Department of Applied Geology, Curtin University, Perth, WA 6845, Australia.[2]Department of Geosciences, Swedish Museum of Natural History, SE-104 05 Stockholm, Sweden, [3]RSES, ANU, Canberra 0200, Australia, [4]Centre for Microscopy, Characterisation and Analysis, University of Western Australia, 35 Stirling Highway, Perth, WA, 6009, Australia

Introduction: The highly radiogenic nature of lunar Pb was recognized from analysis of the first lunar samples [1] and is attributed to a profound loss of Pb early in the history of the Moon resulting in very low initial concentrations of Pb in most lunar rocks. This Pb depletion proved to be detrimental for U-Th-Pb isotopic studies of lunar rocks, because it (i) requires analysis of extremely low quantities of Pb, (ii) complicates corrections for terrestrial contamination and (iii) makes difficult separation of so-called initial Pb (present in the samples at the time they formed) from Pb accumulated in situ by the radioactive decay as both components have very radiogenic isotope compositions. This produces large uncertainties in blank and initial Pb corections that impact on the calculated age and inferences about geochemical characteristics such as time-integrated U/Pb and Th/Pb. Despite these problems, the early work contains information about evolution of lunar Pb even if obscured by contamination. The task is to identify samples or parts of the samples where contribution of contamination component is minimal. A way of doing that by utilizing micro-analytical approach is discussed in this presentation.

Mixing of Pb in lunar samples: A typical Pb isotope composition of a lunar sample would represent a mixture of (i) Pb accumulated as a result of in situ decay of U and Th following the sample formation, (ii) radiogenic lunar initial Pb that was present in the sample at the time it formed and (iii) terrestrial Pb introduced during sample handling and processing. It is also possible that some primitive Pb can be introduced as a result of meteoritic bombardment of lunar surface or mobility in the lunar regolith. However, assuming that the contribution of meteoritic Pb is negligible in the majority of the samples in the Apollo collection and lunar meteorites, mixing relationships of Pb in lunar samples would place any set of analyses of these samples within a triangle defined by the three end members in $^{207}Pb/^{206}Pb$ vs. $^{204}Pb/^{206}Pb$ (Fig.1). The ability to extract information regarding the two lunar components relies on the ability to minimize contribution of terrestrial contamination, which appears to be inhomogenously distributed in lunar samples leaving areas in the samples that are entirely or almost entirely free of contamination. These areas will produce compositions that are located at the leftmost side of the triangle (Fig.1). Micro-analytical methods such as SIMS (Secondary Ion Mass Spectrometry) allow identification of such small areas within the samples, although they can not be recognized prior to the analysis, which results in the need of analyzing extra spots (commonly 20 to 40 in the sample) and filtering out those that indicate presence of terrestrial Pb component.
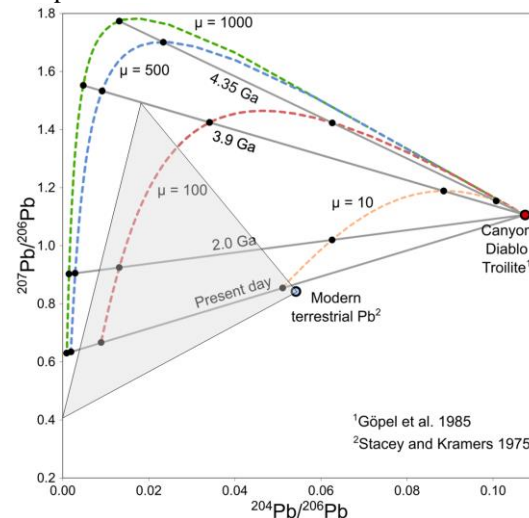

Figure 1. An example of mixing relationships in the lunar Pb compositions. Grey triangle represents three main mixing components (i) in situ accumulated Pb (position of the left corner is a function of age), (ii) lunar initial Pb (position of the top corner is a function of age and $^{238}U/^{204}Pb$ in the source) and (iii) terrestrial contamination

Practical applications: Applying this approach to an Apollo 16 breccia 66095 [2] illustrates the need to filter the data set, but nevertheless produces a well-defined array along the leftmost side of the triangle that can be interpreted as a breccia formation age at 3927±21 Ma (MSWD=1.17, P=0.24). The method can be also used to assess the Pb isotopic system in small clasts within the breccias, as illustrated by the analyses of a 0.5 cm Px-Pl-Kfsp-silica clast from the sample 14083 (Fig.2), which give an age of 3902±21 Ma (MSWD=0.85, P=0.53), indicating that Pb system in this particular clast was completely reset during breccia formation.

In addition to the age information, analyses that are located at the top corner of the triangle (Fig.1) provide information about initial lunar Pb. If a num-

ber of such analyses give a consistent statistically homogenous values of $^{207}Pb/^{206}Pb$ and $^{204}Pb/^{206}Pb$, they
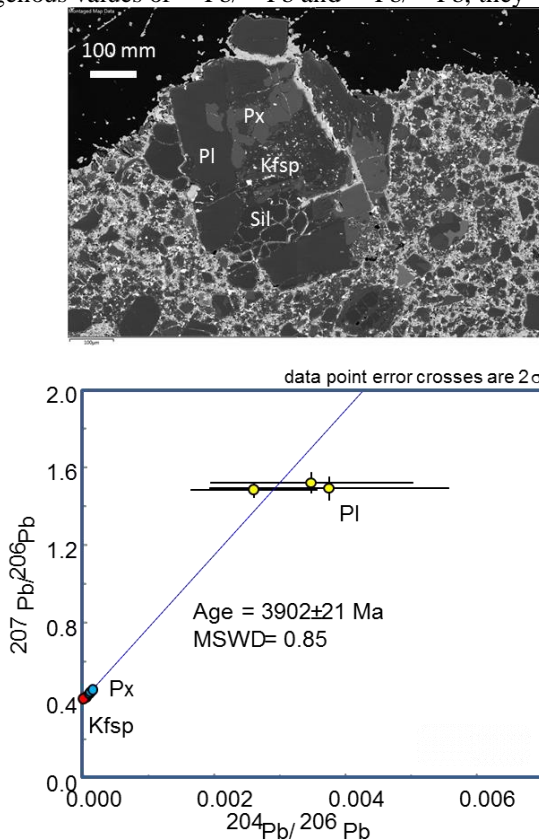

Figure 2. Pb-Pb age of a clast from Apollo 14 breccia 14083

would define the initial Pb isotopic composition with a high degree of confidence. However, it is important to remember that in the general case, an analysis with the highest $^{207}Pb/^{206}Pb$ determines a minimum value for the initial composition. The small number of breccia samples and clasts that we have analysed so far are formed or reset at about 3.9 Ga and show very similar initial compositions with $^{207}Pb/^{206}Pb$ of about 1.5-1.6 and $^{204}Pb/^{206}Pb$ of about 0.003-0.004, suggesting that these compositions characterize an average lunar crust at 3.9 Ga in the region of the Apollo landing sites. It is also very close to the compositions defined by the analyses of two KREEP basalts [3], confirming that many Apollo highland samples are heavily dominated by a highly radiogenic Pb that is most plausibly ascribed to a KREEP component.

In addition to the highlands samples, four mare basalts give ages of 3687±4 Ma (MSWD=1.3, sample 10044), 3242±12 Ma (MSWD=1.4, sample 12038), 3132±9 Ma (MSWD=0.8, sample 12039) and 3194±10 Ma (MSWD=1.4, sample 12063), when similar analytical approach is used [3]. Their initial com-

positions characterize lunar mantle at their respective time of formation. Importantly all these results show a path to the constraining of Pb isotope evolution of major lunar reservoirs.

Additional implications: Constraining the Pb isotope compositions of different lunar reservoirs will help to improve our capacity to address a variety of other issues. One is the possibility of tracking origin of Pb in different samples. For example, initial investigation of Apollo 16 FAS (Ferroan Anorthosite Suite) sample 62236, using SIMS indicates that the most of Pb in the sample is associated with the highly brecciated areas surrounding larger fragments of plagioclase, pyroxene and olivine (Fig.3). The isotopic compositions of this Pb as well as some present in olivine and a few small sulphide grains found in the sample fall along the mixing trend between lunar crustal Pb at 3.9 Ga ($^{207}Pb/^{206}Pb$ of about 1.5-1.6 and $^{204}Pb/^{206}Pb$ of about 0.003-0.004) and terrestrial Pb. This suggests that the majority of Pb currently contained in the sample was introduced during a 3.9 Ga impact that has brecciated the anorthosite.
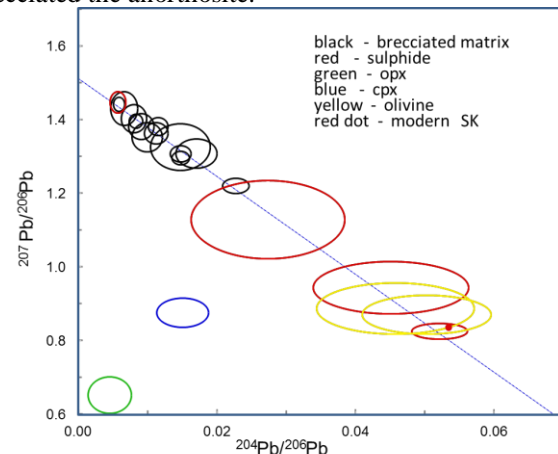

Figure 3. Preliminary Pb-Pb data for Apollo 16 FAS sample 62236.

Analytical spots in plagioclase as well as the majority of those made in pyroxene show extremely low Pb counts that just slightly exceed background level. However, two pyroxene analyses with the higher Pb content trend towards the vertical axis intercept corresponding to an age between 4.3 and 4.4 Ga, indicating that larger pyroxene crystals in the sample may preserve primary Pb and the primary crystallization age of the sample might be extracted with additional analytical work.

References: [1] Silver L.T. (1970), *Proc. Apollo 11 LSC*, 1533-1574, [2] Snape J. F. et al. (2015) *LPS XLVI*, Abstract #1827, [3] Snape J. F. et al. (2015) *78th MetSoc Meeting*, abstract #5236